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Field Evaluation and Design Considerations of Aerobic Digestion

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FIELD EVALUATION

AND

DESIGN CONSIDERATIONS

OF

AEROBIC DIGESTION

by

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ABSTRACT

A survey of aerobic digesters used to stabilize waste sludges from seven water pollution control plants in the Province was conducted over an eighteen month period. Air flow rates of 20 cfm/1000 cu ft of digester capacity were inadequate for both mixing and oxygen requirements in certain installations. Air flow rates determined on the basis of sludge age and solids concentrations indicate that rates of approximately 50 cfm/1000 cu ft of digester capacity are required. To produce a stable sludge, a total sludge age in excess of 120 days is required. To effect sludge concentration and to provide the necessary sludge age, a two stage digester should be provided for all plants except the extended aeration modification of the activated sludge process.

The reduction of volatile solids is not a practical indicator of digested sludge stability. Digesting sludge stability is best indicated by the specific oxygen uptake rate; this rate is temperature dependent. Operational problems can result from temperature extremes in the digester; however, temperature variations can be minimized by the physical design of the plant.

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INTRODUCTION

Current design of water pollution control plants is primarily concerned with the production of high quality effluents. In achieving this goal by removing the organic pollutants, large quantities of sludge are produced that cannot normally be disposed of without some means of pre-treatment. The normal practice has been to anaerobically digest waste sludge to render it less noxious prior to ultimate disposal. Since the anaerobic sludge digestion process is efficient only under controlled conditions of temperature and pH, relatively sophisticated process equipment and adequate supervision must be provided to maintain the necessary process conditions. Many of the smaller communities in Ontario are unable to provide such a system because of the cost involved. To provide for sludge treatment in such cases, the aerobic digestion process has been used in a number of new or modified treatment plants built within the last five years. This process basically consists of aerating waste sludge in an unheated open tank. Minimal supervision is required since process failure and hazardous operating conditions associated with the anaerobic digestion process do not exist. The simplicity of the aerobic digestion equipment results in both a lower initial cost and lower maintenance costs.

The design criteria on which aerobic digesters have been based were derived from a number of laboratory studies. However, the conditions of these studies were idealized and are seldom realized in full scale plants.

This project was undertaken to ascertain the validity of these design parameters as well as to evaluate the performance of the aerobic digestion process and the mechanical designs employed. The aerobic digestion process at seven treatment plants was evaluated and forms the basis of this report.

Particular areas that were investigated included biological oxygen requirements, methods of operation, types of treatment plants preceding the aerobic digester, the practical operating range for suspended solids concentration, supernatant quality, digested sludge characteristics, disposal

methods following digestion, volatile solids destruction, seasonal operating problems, and operational problems related to ether soluble materials and metals.

The information obtained is intended to be used in the design of future plants so that the aerobic digestion process can be efficiently employed where applicable and avoided where process or cost limitations would make it unsuitable.

LITERATURE REVIEW

In recent years, due to the increase in the number of extended aeration and contact stabilization treatment plants, aerobic digestion has been receiving increasing attention. Most applications of the aerobic digestion process have been used to stabilize waste sludge from modified activated sludge systems operating without primary settling. The basis for the design of these digesters was derived from a number of laboratory investigations of aerobic digestion.

Heukelekian (10) in 1933, compared aerobic and anaerobic decomposition of sewage solids for various detention times at 20°C. His results indicated that the destruction of volatile matter is greater under aerobic conditions than under anaerobic conditions at 20°C. The higher volatile matter destruction under aerobic conditions was attributed to a great extent to the higher percentage destruction of fats and nitrogenous materials. These findings substantiated Tenney and Waksman's claim that the rate of aerobic decomposition is greater than the anaerobic rate under certain conditions (29).

Hostetler and Malina (11) reported similar percent reductions of the volatile solids (VS) in the feed sludge for both aerobic stabilization and anaerobic digestion at an organic loading of 0.14 pounds of volatile solids per day per cubic foot (lb VS/day/cu ft) of digester capacity. Sludge drainability data indicated that the aerobically treated sludge and the anaerobically treated sludge exhibited similar drainage characteristics. At higher organic loadings, anaerobically digested sludges drained better than the aerobically digested sludges. Very little odour was produced by either digested sludge while drying, although the feed sludge produced obnoxious odours.

Jaworski, Lawton and Rohlich (14) studied the aerobic stabilization of mixtures of primary and waste activated sludges over a range of organic loadings, detention times and temperatures. Their results indicated that reduction of volatile solids is greater at higher temperatures and at lower loadings. They reported a reduction in volatile solids of 21 percent at a detention time of 5 days at 20°C.

After a detention time of 15 days at 20°C, the reduction in volatile solids was 43 percent and after 60 days at 20°C it was 46 percent. The data indicated that the maximum practical loading rate, based on percent reduction in volatile solids, is approximately 0.10 lb VS/day/cu ft. The digested sludges produced little odour during the drying process and the drainability of sludges digested for periods greater than 5 days was satisfactory.

The findings of Lawton and Norman (17) agree closely with those of Jaworski et al. (14). These data show a significant increase in the volatile solids reduction with increased loading rate up to 0.094 lb VS/day/cu ft. But, when the loading rate increases above 0.094 to 0.1124 lb VS/day/cu ft, there is a noticeable decrease in the reduction of volatile solids.

Eckenfelder (9) studied the aerobic stabilization of waste activated sludge from a conventional activated sludge plant. At the end of 7 days aeration at 25°C the data indicated a 38 percent reduction in volatile suspended solids (VSS) and a decrease of 48 percent in the mixed liquor chemical oxygen demand (COD).

Ackers (1) in 1959, investigated some of the factors that may influence the auto-oxidation rate (endogenous respiration) of biological sludge. He considered two primary factors:

(a) the effect of the mean sludge age (the weight of volatile suspended solids in the system divided by the weight of volatile suspended solids added daily) on the auto-oxidation rate;

(b) the effect of separate aeration (aerobic digestion) of the mixed liquor without additional substrate being added during the aeration period.

He reported higher auto-oxidation rates for sludges of lesser age and observed that the rate of change of auto-oxidation is considerably less than the rate of change of sludge age.

Washington and Symons (31) and Kountz and Forney (16) have observed that total oxidation is not technically possible and that there is a limit to the amount of reduction attainable. They reported that if aeration is continued for an extended period, a residue is produced that consists of inorganic compounds that are resistant to further biological destruction. Results from a study of aerobic digestion conducted at the P.F. Morgan Sanitary Engineering Laboratory, State University of Iowa (7), indicate that as the sludge age of the sludge being added to the aerobic digester increases, the percent removal decreases. Thus, it would appear that a sludge age could be attained beyond which no significant reduction of volatile suspended solids would occur.

Hostetler and Malina (11) in 1964, studying the aerobic digestion of primary sludge under three volatile solids loadings, noted a significantly higher reduction of volatile solids at the lower loading. They reported a 38 percent reduction of volatile solids at a loading of 0.14 lb VS/day/cu ft and about 25 percent reduction of volatile solids at loadings of 0.17 and 0.20 lb VS/day/cu ft. They indicated that at the higher loadings the digestion units were not receiving an adequate supply of oxygen. The weight of volatile solids broken down however, was about the same at the three organic loadings (about 12,000 mg/l). They concluded that a limited amount of organic solids may be degraded under aerobic conditions during a 15 day detention time at 35°C regardless of the organic loading.

Contrary to the results of Jaworski et al. (14), Burton and Malina (5) reported that the aerobic stabilization unit is capable of more efficient decomposition of solids at a loading of 0.14 lb VS/day/cu ft than at 0.10 lb VS/day/cu ft. However, the reductions of volatile solids were calculated by dividing the difference in the volatile solids concentration of the feed sludge and the stabilized sludge by the concentration of volatile solids in the feed sludge:

$$\text{Percent Reduction VS} = \frac{\text{Feed VS} - \text{Stable VS}}{\text{Feed VS}} \times 100$$

Based on the data published by Hostetler and Malina (11), they also appear to have used this equation for calculating the reduction of volatile solids; this equation applies only to a

batch process while both studies dealt with continuous processes. Using the equation,

$$\text{Percent Reduction VS*} = \frac{\text{VS Feed} - \text{VS Stable}}{\text{VS Feed} - (\text{VS Feed} \times \text{VS Stable})} \times 100,$$

which is derived from a mass balance on a continuous system and the data of Burton and Malina (5), the aerobic digester loaded at the lower rate shows a greater reduction of volatile solids.

The above equation for continuous feed systems has been adopted by the Water Pollution Control Federation's Subcommittee on Sludge Digestion (32) and variations of this equation have been used by several authors to calculate the reduction in volatile solids during digestion (4) (26) (27) (30) (32).

Dreier (8) has reviewed the performance of the aerobic digestion process at several field installations. The digested sludges produced were stable and did not exhibit any obnoxious odours when left standing for several weeks. Based on the field studies and on a literature evaluation, he concluded that 15 days volumetric (hydraulic) detention should be provided for waste activated sludge alone at a temperature of 60°F (15.5°C); for mixtures of primary and waste activated sludge a minimum displacement time of 20 days and a maximum loading of 0.10 lb TS/cu ft/day were suggested for design in a moderate climate. Longer detention times would be necessary in colder climates or if sludge storage is to be provided.

In many European countries the design of aerobic digesters is based on a hydraulic detention time of 5 days (3) (15) (23). In the United States the "Rapid Bloc" process has been used in more than one hundred plants with aerobic digesters designed for 7.5 days detention (23). In Quebec, the first aerobic digestion units were designed on 5 days detention (23). Following a decision by the Quebec Water Board, they are now designed on 10 days detention. There are no data available however, to indicate that adequate stabilization is achieved.

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*Volatile solids (VS) values are expressed as a fraction percent of the total solids (TS).

If the digester is not sufficiently large for this to occur, the digested sludge may putrefy when applied to the land or a drying bed. This fact is recognized in England and although 19 days hydraulic detention time is considered adequate, the design of aerobic digesters has been based on a detention time of 29 days (22).

Lawton and Norman (17), discussing previous studies and Norman's continuation of the studies of Jaworski et al. (14), reported on the effect of temperature and aeration time on digestion of a mixture of primary and waste activated sludge. The results, which agreed closely with those of Jaworski et al. (14), indicated the reduction of volatile solids increases significantly with increasing detention time and increased temperature between 15°C and 30°C.

Barnhart (2) studied the aerobic digestion of a variety of domestic and industrial sludges and reported that the reductions of volatile suspended solids obtained were comparable to anaerobic digestion. He concluded that the effects of temperature below 20°C are significantly retardant to aerobic digestion. Reyes and Kruse (27) aerobically digested night soil and also found that the rate and degree of stabilization vary directly with the digestion temperature.

The work of Woodly on temperature effect was reviewed by Viraraghavan (30). Woodly's data indicated that primary sewage sludge can be aerobically stabilized under mesophilic (35°C) or thermophilic (52°C) conditions and that the percentage reduction in volatile solids was higher in the mesophilic than in the thermophilic range. The mesophilic oxidized sludge settled readily and gave a clear supernatant, whereas thermophilic oxidation was more efficient in the destruction of nitrogenous material.

Aerobic digestion studies using waste sludges from different plants have shown the rate of volatile solids reduction to change by a factor of two for each 10 Centigrade degree temperature change within the range between 0° and 35°C (6) (9) (18) (28) (30). Data reported in the literature indicate that a sludge age of approximately 15 to 18 days at 20° would be sufficient to accomplish acceptable digestion (2) (8) (14) (17) (18) (30). Because of the temperature effect, a sludge age of approximately 30 days would be needed to accomplish the same degree of stabilization at 10°C.

For the aerobic digestion of waste sludge, the air requirements will be related to the oxygen requirements for the biological oxidation reactions and to the oxygen transfer efficiency of the aeration equipment. For design purposes, an air supply of 15 to 20 cubic feet per minute per 1,000 cubic feet (cfm/1000 cu ft) of digester liquid capacity is frequently used to determine the air requirement for aerobic digesters. This figure is claimed to adequately meet the requirements for oxidation and mixing (8) (18).

Studies on the specific uptake rate of sewage sludge have been conducted by several investigators. Barnhart (2) showed a variation in oxygen requirements for mixed primary and activated sludge from domestic sewage of 2.5 to 3 milligrams of oxygen per gram of volatile suspended solids per hour (mg O_2/gm VSS/hr). Carpenter and Blosser (6) reported after the first 24 hours aeration the oxygen requirements of secondary sludge (activated sludge) during aerobic digestion were reasonably stable and found to be in the range of 2.5 to 6 mg O_2/gm VSS/hr. Placak and Ruchhoft (21) and Eckenfelder (9) reported various activated sludges to have specific uptake rates of 2 to 7 mg O_2/gm VSS/hr, depending on the sludge age. Loehr (18) noted that where sludge synthesis is required, such as when raw sludge is included in the feed to the digester, the high cost of supplying air is a major disadvantage to the aerobic digestion process.

Randall and Koch (25) investigated the factors affecting dewatering of aerobically digested sludge from twelve full scale contact stabilization plants on open air sand drying beds. The use of paved sludge beds of centre drain design was also studied. The standard sludge used for comparative purposes was from a plant operating at only 10 percent of its design flow. However, their findings indicated that the principal mechanism of dewatering was drainage, rather than evaporation. Thus paved drying beds do not perform as well as sand drying beds. Sludges from digesters with low dissolved oxygen (DO) levels (less than 1 mg/l) dewatered poorly. Dewatering rates also decreased with increasing solids concentration. They found that an aeration rate of 0.12 lb air/hr/cu ft (approximately 25 cfm/1000 cu ft) satisfied mixing and biological oxygen requirements for most digesting sludges. Sludge ages and corresponding solids concentrations for the various sludges were not reported. Drying

times ranged from 7 to 14 days to produce a dried sludge with a moisture content of 15 percent or less. The average daily temperature throughout most of this study was 85°F (30°C).

Murphy (19) studied the effects of aeration on the filterability and drainability of mixtures of primary and waste activated sludge for different detention times at 15°C. He concluded that the reduction of volatile solids with digestion periods up to 6 days was not appreciable, and that vigorous aeration for short periods reduced the filterability and settleability of the sludge.

Some investigators have reported that sludges digested aerobically do not always settle well in the supernating process. Jaworski et al. (14) and Lawton and Norman (17) observed that few of the sludges digested exhibited good settling characteristics, with good settleability obtained only in those samples digested for 60 days at 15°C and for 10 days at 35°C.

Carpenter and Blosser (6), when investigating aerobic decomposition of domestic sludge and secondary paper mill sludges, observed similar results. After extended aeration periods, on some occasions, they encountered floating sludge due to entrained air and supernating could not be accomplished without degassification.

Normally aerobic digestion produces a high quality supernatant that has a lower biochemical oxygen demand (BOD) and nutrient level than those from anaerobic digestion. The results of several investigations indicate that BOD values would be less than 100 mg/l (2) (8) (14) and range as low as 10 mg/l (13).

Irgens and Halvorson (13) investigated the removal of plant nutrients by means of aerobic stabilization of primary sludge. They reported that the aerobic digestion process ties up the available nitrogen and phosphorus so that practically none remains in the supernatant liquor.

Several authors have indicated that the concentration of nitrate nitrogen in digester supernatant liquor gradually increases as digestion progresses. Jaworski et al. (14) reported an increase in nitrate content from zero at 5 days

detention to 64 mg/l at 10 days, 170 mg/l at 30 days, and 835 mg/l at 60 days when mixed primary and waste activated sludge was aerobically stabilized at 15°C. Randall and Koch (24) extended the digestion periods of aerobically digested activated sludges obtained from five field installations and reported a progressive increase in supernatant nitrate content with length of digestion period.

Jaworski et al. (14) also noted that the pH of digesting sludge increased to a maximum of 8 for detention periods up to 10 days and then gradually declined to a value near 5.

Kehr (15) has noted that because of economics, sludge stabilization is not carried out to complete mineralization but is interrupted before it is reached. In the anaerobic digestion process, the "technical digestion limit", according to Imhoff and Fair (12) is defined as the point where 90 percent of the total gas is produced. Similarly, aerobic stabilization of sludge is not carried out to complete mineralization, but only to a certain degree of stabilization. Up to now there has been no definite index for the degree of aerobic sludge stabilization.

Kehr (15) suggests that the intensity of respiration in sludge, or "reductase activity" of sludge, might be able to serve as a useful index for the degree of aerobic stabilization. According to Okazaki and Kato (20), the dissolved phosphate concentration in digested sludge supernatant liquor increases with the progression of aerobic stabilization and the release of soluble orthophosphate would serve as a favourable index for aerobic stabilization. However, depending on many variables including pH, dissolved oxygen, and cations present and their concentration, the orthophosphorus may be chemically fixed in the sludge solids; hence, the release of orthophosphate phosphorus from digesting sludge can not always be predicted.

FIELD STUDY PROCEDURES

Sampling Procedures

Routine samples of waste sludge (influent to the digesters), supernatant and digester contents were submitted over a twelve month period by the treatment plant operators. In addition, each plant was visited repeatedly to ascertain the operating conditions and problems of the digesters. As well as field measurements at these times, additional samples were taken for analyses not performed on a routine basis. Flow data were obtained from plant operating records.

Routine Sample Analyses

All samples were analyzed for pH, COD, total solids, total volatile solids, total Kjeldahl nitrogen, and total phosphorus. Supernatant samples were also analyzed for BOD, filtered BOD, suspended solids, nitrate nitrogen and orthophosphate phosphorus.

Additional Analyses

Tests performed in the field included pH, temperature, dissolved oxygen, oxidation reduction potential (ORP), nitrate nitrogen and oxygen uptake rates of the digesting sludges. Additional samples were taken for ether solubles and heavy metals analyses (chromium, aluminum, zinc, copper, nickel, lead, cadmium, manganese and iron). The amount of solids deposition in the digesters and other tanks was determined by probing the bottom of the tanks with a pole. The depth of the bottom deposits was determined by forcing the pole through the deposits to the tank bottom. Bottom samples were taken with an Ekman dredge and analyzed for pH, ORP (in the field), COD, total and total volatile solids, total Kjeldahl nitrogen and total phosphorus.

Samples of the treatment zones preceding the aerobic digesters (aeration tanks in conventional plants and contact and reaeration zones in contact stabilization plants) were

taken for oxygen uptake rates and suspended and volatile suspended solids. The oxygen uptake rate of several primary sludges was also determined.

DESCRIPTION OF TREATMENT FACILITIES

A description of the facilities of each of the treatment plants that was included in the survey of operating aerobic digesters in Ontario follows. The design data of these plants and particularly the aerobic digesters are presented in Table 1.

Aurora WPCP

The wastewater treatment facilities of the Town of Aurora were recently modified and expanded to accommodate the increase in population. The conventional activated sludge plant was modified to operate as a contact stabilization unit. The existing anaerobic digester and aeration tanks of a previous plant were to be used for aerobic digestion of waste sludge from the contact stabilization plant. The final clarifier of the old installation was to serve as a sludge thickener for digested sludge. However, the old aeration tanks are only occasionally used for sludge digestion because of operating difficulties.

The design air supply for the second stage aerobic digester (former anaerobic digester) was based on the organic loading from the first stage digester. The air flow to the second unit is consequently 480 scfm (8.4 cfm/1000 cu ft of digester capacity) while the first stage digester was designed for an air supply of 25 cfm/1000 cu ft of digester capacity. This was to provide excess air for agitation.

Ultimate sludge disposal is effected by truck haulage and land disposal.

Bolton WPCP

The treatment facilities of the Village of Bolton were designed to replace the former trickling filter system. The treatment plant utilizes the conventional activated sludge process with treatment of both primary and waste activated sludge provided by a single stage aerobic digester. Ultimate

disposal of waste digester solids is effected by discharge to a sludge drying bed followed by truck haulage and land disposal.

Kleinburg WPCP

The sewage treatment facilities for the Kleinburg Estates Subdivision in the Township of Vaughan utilize the extended aeration modification of the activated sludge process. The plant is designed to provide twenty four hours retention and is preceded by a flow equalization tank with a retention time of twenty three hours at design flow. Waste activated sludge is treated in a single stage aerobic digester. Ultimate disposal of waste sludge from the digester is effected by truck haulage followed by land disposal.

Penetanguishene WPCP

The Town of Penetanguishene WPCP was designed to operate as the contact stabilization modification of the activated sludge process. The entire treatment section of the plant, except for the grit removal facilities, is contained in a single unit consisting of two concentric tanks. The centre tank serves as the final clarifier while the remaining annulus contains the mixing (or contact) zone, the reaeration zone, two stages of the aerobic digester and the chlorine contact chamber. Ultimate sludge disposal from the second stage digester is effected by truck haulage and land disposal.

Picton WPCP

In 1964 the sewage treatment facilities of the Town of Picton were converted from a trickling filter system to the contact stabilization modification of the activated sludge process. The settling tanks of the existing plant were retained as a part of the new plant, one tank as a final clarifier of the new plant and the other tank as a spare clarifier and for periodically wasting sludge to the digesters. The existing anaerobic digester was converted to an aerobic digester by removing the gas collection equipment and installing

air diffusers. The remainder of the plant, except the chlorine contact chamber, is contained within two concentric tanks. The centre tank is utilized as the first stage aerobic digester while the remaining annulus contains the mixing and reaeration zones. Tank truck haulage followed by land disposal is used for ultimate sludge disposal.

West Don WPCP

The West Don WPCP in the Township of Vaughan is a conventional activated sludge system and receives wastes from a large railway classification yard and an adjacent industrial park. Sludge from the primary clarifier as well as waste activated sludge is treated in a single stage aerobic digester. Digested sludge is wasted to drying beds and removed by truck haulage to a sanitary landfill area.

Unionville WPCP

The treatment facilities of the Police Village of Unionville in the Township of Markham are similar to the facilities of Bolton in that the plant consists of two identical conventional activated sludge plants operating in parallel. Primary and waste activated sludge are aerobically digested in a separate two stage digester. Waste digested sludge is ultimately disposed of by truck haulage and land disposal.

TABLE 1

PHYSICAL PLANT DATA

Plant Location	Plant Type	Design Flow IMGD	Present Flow IMGD	Digester Type	Digester Capacity cu ft	Tank Configuration	Tank Dimensions ft
Aurora	Contact Stabilization	1.85	1.4	Two Stage	#1-57250 #2-10800	Circular Rectangular	57X26.5 40X9X10 (three tanks)
Bolton	Conventional	0.50	0.25	Single Stage	15700	Circular	36.25X15.25
Kleinburg	Extended Aeration	0.050	0.025	Single Stage	1366	Rectangular	11X10X14
Penetanguishene	Contact Stabilization	0.334	0.4	Two Stage	#1- 8863 #2- 4431	Annular Segment Annular Segment	(62-30)X92°X15 (62-30)X46°X15
Picton	Contact Stabilization	0.54	0.9	Two Stage	#1-10450 #2-13500	Circular Circular	32X13 28X22
Unionville	Conventional	0.40	0.03	Two Stage	#1-11540 #2- 6060	Circular Segment Circular Segment	40X124°X14 40X236°X14
West Don	Conventional	0.334	0.37	Single Stage	9720	Circular	30X14

ANALYTICAL RESULTS

Routine Analyses

The results of all routine analyses are presented in Tables 2-4. The average and range of the results for each type of sample appear in the same table. For each test in the table of average results, the number of samples analyzed is shown in parentheses following the average result. The range of results applies to the same number of determinations. No data are presented for waste sludge to the digester for the Kleinburg plant or for supernatant from the Picton digesters since these samples were seldom available due to the batch method of operation.

Additional Analyses

The results for the metal analyses are presented in Appendix I. Results for bottom sludge samples appear in Table 5.

TABLE 2

CHEMICAL CHARACTERISTICS OF WASTE SLUDGES (INFLUENT TO DIGESTER)

Analyses	Penetang	Bolton	Aurora	West Don	Unionville	Picton
Average of Results						
pH	6.8 (46)	6.7 (27)	7.0 (9)	6.3 (8)	6.5 (6)	6.8 (4)
Total Solids	8550 (46)	29500 (28)	14200 (9)	41600 (10)	40400 (6)	19900 (4)
Total Volatile Solids	5210 (46)	14300 (28)	8020 (9)	29200 (10)	22000 (6)	11800 (4)
COD	7900 (46)	23700 (27)	12700 (9)	63000 (10)	22600 (6)	14400 (4)
Kjeldahl N	397 (43)	990 (27)	580 (9)	3540 (10)	1180 (6)	810 (4)
Total P	144 (46)	470 (27)	450 (9)	990 (10)	565 (6)	260 (4)
Range of Results						
pH	6.5-7.1	6.2-7.2	6.4-7.4	5.5-6.9	6.3-6.7	6.2-7.0
Total Solids	4320-13900	4560-86600	10900-16200	32500-59400	1960-65000	3890-40500
Total Volatile Solids	1060-10800	3050-29300	6470-9650	19400-43400	870-63000	2600-31700
COD	6050-11400	4300-54800	8400-24000	32000-92700	1600-37500	1760-41000
Kjeldahl N	27-675	150-2200	245-920	1290-18000	92-2000	200-2200
Total P	23-630	61-1100	359-555	434-1340	27-940	73-620

(All results in mg/l except pH)

TABLE 3

CHEMICAL CHARACTERISTICS OF DIGESTER SLUDGES

Average of Results											
	Penetang		Bolton	Aurora		West Don	Unionville		Picton		Kleinburg
	#1	#2		#1	#2		#1	#2	#1	#2	
pH	6.8 (37)	6.2 (39)	7.1 (32)	7.5 (13)	7.3 (11)	7.6 (13)	6.7 (12)	6.6 (12)	6.5 (13)	6.9 (14)	7.1 (6)
COD	16400 (36)	33200 (38)	18400 (32)	16900 (13)	19400 (10)	27400 (14)	14600 (12)	14100 (12)	15100 (13)	21200 (14)	14200 (6)
Total Solids	18500 (37)	39400 (39)	28400 (32)	25300 (13)	28600 (11)	27600 (14)	31200 (12)	30400 (12)	13600 (13)	22000 (14)	35500 (6)
Total Volatile Solids	10400 (37)	21500 (39)	13800 (32)	13800 (13)	15100 (11)	16200 (14)	11400 (12)	12700 (12)	9500 (13)	14300 (14)	10500 (6)
Kjeldahl N	735 (34)	1460 (36)	840 (32)	1150 (13)	1420 (11)	1410 (14)	960 (12)	660 (12)	820 (13)	1230 (14)	640 (6)
Total P	325 (37)	536 (39)	447 (32)	800 (13)	900 (11)	755 (14)	510 (12)	490 (12)	330 (12)	485 (13)	440 (6)
Orthophosphate P	25 (3)	70 (3)	38 (4)	2 (2)	7.0 (3)	1.3 (3)	52 (3)	56 (3)	46 (2)	40 (2)	48 (2)

(All results in mg/l except pH)

cont....

TABLE 3 (cont)

Range of Results											
	Penetang		Bolton	Aurora		West Don	Unionville		Picton		Kleinburg
	#1	#2		#1	#2		#1	#2	#1	#2	
pH	6.1-7.3	5.4-6.8	6.7-7.4	7.1-7.7	6.9-7.6	6.7-8.4	6.1-7.2	5.9-7.1	5.8-7.0	6.3-7.3	6.5-7.6
COD	8330-32100	18500-51000	8100-37000	12500-21300	8600-24900	11800-44000	7900-22000	6710-21000	7060-30600	3800-45100	1900-22000
Total Solids	10200-40000	11800-59800	10000-57600	23000-38700	15900-35800	10900-36300	10200-49000	11700-47600	7650-22000	4040-44100	6200-58400
Total Volatile Solids	5630-22000	6520-36000	5580-35600	11600-25700	7780-20600	6040-30300	6200-16500	5400-29300	4920-15900	3470-29600	1940-18900
Kjeldahl N	25-1600	240-4100	360-1600	825-1730	570-1820	700-2450	335-2800	323-1000	390-1700	195-3100	115-1250
Total P	112-700	10-1010	75-1100	111-950	89-1250	191-1510	235-780	179-810	175-685	91-1080	56-700
Orthophosphate P	19-35	34-113	7-46	1.4-2.6	0.6-19	0.52-3.2	33-63	36-63	25-67	29-51	19-76

(All results in mg/l except pH)

TABLE 4

CHEMICAL CHARACTERISTICS OF DIGESTER SUPERNATANT

	Average of Results						
	Penetang #1	Penetang #2	Bolton	Aurora	West Don	Unionville	Kleinburg
pH	6.7 (46)	5.9 (7)	7.2 (22)	7.7 (10)	7.7 (6)	7.4 (3)	7.2 (1)
BOD	237 (46)	112 (6)	1700 (15)	241 (10)	681 (4)	9 (2)	70 (1)
Filtered BOD	21 (43)	17 (7)	94 (17)	103 (10)	183 (3)	4 (2)	15 (1)
COD	820 (46)	1040 (7)	8140 (22)	620 (10)	2200 (6)	498 (3)	228 (1)
Susp. Solids	975 (39)	1200 (7)	11500 (19)	453 (9)	870 (3)	46 (3)	280 (1)
Kjeldahl N	72 (42)	57 (7)	398 (22)	150 (10)	266 (6)	10 (3)	13 (1)
Total P	58 (45)	98 (7)	241 (22)	19 (10)	55 (6)	22 (3)	24 (1)
Orthophosphate P	27 (46)	64 (7)	27 (22)	2.5 (10)	13 (6)	19 (3)	7 (1)

(All results in mg/l except pH)

cont....

TABLE 4 (cont)

Range of Results						
	Penetang #1	Penetang #2	Bolton	Aurora	West Don	Unionville
pH	5.7-7.5	5.6-6.1	6.7-7.7	7.3-7.9	7.2-8.0	7.2-7.5
BOD	5-3200	16-370	27-6350	95-380	260-1180	5-13
Filtered BOD	3-127	8-25	7-270	20-200	110-280	3-5
COD	24-9400	200-5160	70-25500	372-830	885-4500	85-1300
Susp. Solids	9-10300	119-6750	46-41800	270-795	552-1410	19-61
Kjeldahl N	4.1-480	16-170	15-1350	88-300	40-650	2.9-23
Total P	2.1-400	39-215	9-930	11-35	13-124	18-31
Orthophosphate P	1.2-58	1-120	3-55	0.7-3.5	0.4-29	15.5-26

(All results in mg/l except pH)

June 12, 1973.

MEMORANDUM:

TO: Mr. F.A. Voege
Executive Director

FROM: A.J. Harris, Director
Research Branch.

RE: RESEARCH PUBLICATION NO. W35 - "THE EFFECTS OF INFLUENT ALUM INJECTION ON THE EFFLUENT FROM CONTINUOUS DISCHARGE LAGOONS".

According to your instructions, we are forwarding herewith three copies of Research Publication No. W35, "The effects of Influent Alum Injection on the Effluent from Continuous Discharge Lagoons", for Ministerial approval.

A. J. Harris

....
A. J. Harris.

AJH:sjr

TABLE 5

CHEMICAL CHARACTERISTICS OF BOTTOM SLUDGES

pH	COD mg/l	Total Solids mg/l	Total Volatile Solids mg/l	Volatile Fraction percent	Total Kjeldahl mg/l	Phosphorus mg/l Total	Phosphorus mg/l Ortho-phosphate	ORP E_h mv
Penetanguishene - Reaeration Zone								
6.7	48000	645000	33000	5.1	875	800	83	-
Bolton - Aerobic Digester								
6.3	68500	112000	45000	40.2	2000	1800	-	-
6.0(5.9)*	75000	107000	55000	51.4	3200	1180	-	70
6.2(6.1)*	83000	109000	47700	43.8	5600	1370	-	50
6.4(6.5)*	75600	698000	75300	10.8	1680	2470	422	35
Aurora - Aerobic Digester								
7.6(7.5)*	15400	24900	12900	51.8	1350	910	-	160
Unionville - Aerobic Digesters								
6.6(6.8)*	37100	220000	30000	13.6	1230	1700	55	75
6.8(7.2)*	44400	430000	24000	5.6	1800	2900	19	45
Picton - Aerobic Digester (Stage 2)								
6.4	28000	60000	37000	61.7	2850	960	-	460
Kleinburg - Aerobic Digester								
7.0	45000	162000	33000	20.4	3250	2400	110	-

*Denotes field measurement

DISCUSSION OF RESULTS

A. PROCESS PERFORMANCE

The data on the hydraulic and organic loadings, sludge age, and air supply for the digesters are presented in Table 6. Because of the irregular sludge wasting procedures followed at some of the plants, loadings and sludge ages could vary considerably from the average values presented. However, the data reflect the present state of these units with respect to their design conditions.

Digester Sludge Characteristics

Solids Concentration

The solids concentration of aerobically digesting sludge has varied from less than 1 percent total solids to almost 6 percent total solids (total solids are reported since the dissolved solids concentration is usually less than 0.2 percent and more often less than 0.1 percent). The variation is due to the methods of wasting sludge to the digester, the type of sludge wasted, and the frequency of ultimate sludge disposal. Most digesters operate at greater than 2 percent total solids (except the first stages at Penetanguishene and Picton). At solids concentrations greater than 3 percent, difficulties with sludge settling and supernatant removal are frequently encountered. Thus it is advisable to operate a two stage system. The first stage should maintain a low solids concentration (1.5 to 3 percent total solids) to permit frequent supernatant removal and also to minimize the oxygen requirements where the maximum specific oxygen uptake rate exists. The second stage should have a higher solids concentration (greater than 3 percent total solids) to permit concentration of the sludge where the minimum specific uptake rate prevails and where the operating demands are less stringent (i.e. supernatant removal on an infrequent basis, weekly or monthly rather than daily).

TABLE 6

PROCESS DATA

Plant and Digester	Digester Hydraulic Retention (Days)	Digester Sludge Age (Days)	Digester Loading Design lb VS/ cu ft/day	Digester Loading Actual lb VS/ cu ft/day	Air Supply Design cfm/ 1000 cu ft	Air Supply Actual cfm/ 1000 cu ft
Penetanguishene						
#1 Digester	14	30	0.08	0.024	20	-
#2 Digester	-	-	(overall)	-	20	-
Bolton	30	29	0.0256	0.025	25	19
Aurora						
#1 Digester*	-	-	0.024	-	23	(23)
#2 Digester	20	30	(overall)	0.025	8.4	8.4
West Don	60	45	0.05	0.027	25	46
Unionville						
#1 Digester	360	320	0.0166	0.0035	30	-
#2 Digester	-	-	(overall)	-	(both)	-
Picton						
#1 Digester	(65)	(45)	0.0326	(0.012)	19	-
#2 Digester	-	-	(overall)	-	(both)	-
Kleinburg	60	100	0.024	0.020	29	29

*Occasionally used as second stage digester.

Note: Data in parenthesis indicate estimated figures.

pH

The effect of the lowering of pH with long digestion times was observed at Penetanguishene (the longest digestion period in the second stage and the lowest pH) and Aurora. This effect was not observed at Picton. The pH of the Aurora and West Don digester contents was usually higher than any of the others. Both of these digesters normally have an inadequate dissolved oxygen concentration of less than 1 mg/l. Laboratory studies have indicated the pH of aerobically digesting sludge initially rises to about pH 8 and then declines. It is felt that the combination of daily loading and the inadequate air supply of the Aurora and West Don digesters keeps these digesters in the initial stage of digestion by lowering the biological activity which results in the high pH. Both of these digesters are also normally covered with a layer of foam; however, the high pH is not thought to be a cause of foaming since foaming has been observed at low pH values (e.g. Penetanguishene). It is more probable that both the foaming and high pH are a result of the process conditions.

Phosphorus

Though data on the orthophosphate phosphorus content of aerobic digester sludges were not determined on a regular basis, the data available indicate that this phosphorus is approximately 10 percent (8-14 percent) of the total phosphorus; that is, most of the phosphorus is in the sludge solids rather than the liquid. Two extreme cases of this are the Aurora and West Don plants. The orthophosphate phosphorus fraction of the digester sludges of these plants is less than 1 percent of the total phosphorus content. Orthophosphate phosphorus data on the supernatant confirm the data on the digester sludges. These two plants receive a number of industrial wastes. It is felt that the presence of metal wastes accounts for the very low soluble phosphorus (i.e. orthophosphate) concentration in the digesters. At the Aurora plant it has been observed that a substantial removal of phosphorus occurs in the sewage treatment process. Such removals at the West Don plant have not been investigated. The removal at the Aurora plant is probably due to aluminum wastes (See Appendix I). This is suspected because of the extremely high aluminum content in the digesters (approximately 10 percent of the total solids concentration).

As the filtered digester samples show, a very small fraction of the metals in the digester are in solution.

Sludge Settleability

One necessary condition for the effective operation of an aerobic digester is the formation of a settleable sludge. The advantages of good settleability include, the production of a concentrated sludge thereby minimizing the ultimate disposal costs, the production of a high quality supernatant, and minimization of the amount of time the digesting sludge is subjected to anaerobic conditions. The 30 minute settling test is not in general use at plants with aerobic digesters; in fact, its usefulness in the operation of aerobic digesters would be limited to estimating the minimum settling time required to obtain a specific volume of supernatant (i.e. digester capacity for additional waste sludge) or to indicate that sludge wastage from the digester would be advisable due to progressively poorer settleability. Its latter application is doubtful since typical settled sludge volumes are 900 ml in 30 minutes. A longer settling time (e.g. one hour) might be more meaningful for detecting trends in daily settleability changes.

Settleability of aerobically digesting sludges is dependent upon solids concentration, dissolved oxygen concentration, and the type of sludge fed to the digester. It appears that with excessively long retention times and resultant high solids concentrations such as observed at Penetanguishene (approximately two years in the second stage), the settleability of the sludge and the supernatant quality deteriorate. Poor settleability has also been observed when residual DO levels are low (less than 1 mg/l DO).

Volatile Solids Reductions

The volatile solids reductions in aerobic digesters have normally ranged from 10 to 25 percent in first stage or single stage units and up to a maximum of about 45 to 50 percent in two stage digesters. The average results are shown in Table 7. In some cases, the volatile solids fraction has not decreased while in other instances it has increased. This is

TABLE 7

TOTAL VOLATILE SOLIDS REDUCTION

Plant and Digester	Average Volatile Solids Fraction: Waste Sludge to Digester	Average Volatile Solids Fraction: Digested Sludge	Percent Reduction of Total Volatile Solids
Penetanguishene			
#1 Digester	61.0	56.1	18
#2 Digester	56.1	54.6	8
Overall	61.0	54.6	24
Bolton	48.5	48.6	-
Aurora			
#1 Digester	56.6	54.5	10
#2 Digester	54.5	52.7	9
Overall	56.6	52.7	14
West Don	70.3	58.7	41
Unionville			
#1 Digester	54.5	36.5	52
#2 Digester	36.5	41.8	-
Overall	54.5	41.8	40
Picton			
#1 Digester	59.4	70.0	-
#2 Digester	70.0	65.1	20
Overall	59.4	65.1	-

probably due to periodic fluctuations in the volatile fraction of the waste sludge. Only a complete mass balance on the system would show consistent reductions.

The type of sludge wasted to the digester should also be considered. The same percent reduction in volatile solids should not be expected with waste activated sludge from an extended aeration plant as that achieved in digesting primary sludge because of the different initial sludge ages. The volatile fraction in waste sludges with a high initial sludge age is due to a large extent to an accumulation of biologically inert volatile matter. The performance of an aerobic digester therefore cannot and should not be judged on the basis of volatile solids reduction. The only possible exception is a long term batch digestion which under practical operating conditions is never encountered. Table 7 illustrates that the volatile solids reduction does not provide a meaningful operating parameter especially since one of the least stable digester sludges (West Don) shows one of the greatest reductions of volatile solids. The necessary sampling programme for digester control by a mass balance on the volatile matter would be impractical for the smaller treatment plants that would employ the aerobic digestion process.

Supernatant Characteristics

Apart from the stability and concentration of digesting sludge, the next most important aspect of aerobic digestion is the production of a low strength supernatant to minimize any additional load on the activated sludge process. Since the daily flow of supernatant returned to the plant is normally about 1 percent of the total plant flow, the organic load of the supernatant will be insignificant if the organic strength of the supernatant is equivalent to that of the raw sewage. The average results indicate that only the West Don and Bolton plants do not meet these requirements. Both of these digesters are single stage units. The high strength supernatant from the West Don digester is not unexpected considering the loading conditions. The poor quality supernatant of the Bolton digester is primarily due to the high solids concentration, a result of a buildup of solids in the digester to approximately 6 percent.

A high solids concentration in the supernatant does not necessarily indicate a high load to the aeration tanks. In a conventional plant, most of the solids will settle out in the primary tanks and be recycled to the digester. In any other type of plant, the solids concentration in the aeration tanks will be increased but normal control of the mixed liquor solids concentration will minimize the temporary effects of the additional load. The true loading due to the supernatant is represented by the soluble BOD (or filtered BOD) which as can be seen in Table 4, is equal to or less than the organic strength of raw sewage. The loading due to suspended solids in the supernatant will not have the same effect on the plant as a similar concentration from an anaerobic digester. This is because the solids from the aerobic digester are in an endogenous stage of respiration (i.e. an oxidized state) with a lower specific oxygen uptake rate than the activated sludge solids. The solids in an anaerobic digester supernatant are in a reduced state and therefore represent an organic load to an oxidizing environment (i.e. the activated sludge).

While the organic load due to suspended solids in an aerobic digester supernatant is expected to be considerably less than a corresponding suspended solids concentration for an anaerobic digester, a high solids concentration in the supernatant nevertheless represents an inefficiency in the process. The performance at the Bolton WPCP is the best example of such an inefficiency which is caused by the combination of a single stage digester with a conventional activated sludge plant. When a high solids concentration in the digester occurred (approximately 6 percent total solids), the suspended solids concentration in the supernatant rose to over 4 percent. However, the operation of the activated sludge process was not adversely affected since the solids were recovered in the primary settling tanks (the primary sludge concentration rose to 8.6 percent total solids from a usual concentration of 2.5 to 3 percent total solids).

While the concentrations of Kjeldahl nitrogen and orthophosphate phosphorus are higher in digester supernatant (see Table 4) than in raw sewage, the concentration factor is usually five times or less and therefore the total weight of nutrients that could be removed from aerobic digester supernatant is only a small fraction of the total plant nutrient flow (nitrogen and phosphorus). Aerobic digester supernatant

in most installations affords the opportunity of nitrogen removal by denitrification. However, flow considerations indicate that denitrification would be useful only in preventing operating problems in the final clarifier, such as floating sludge due to denitrification, rather than effecting any great reduction of the overall plant nitrogen output in the effluent.

High nitrate concentrations (50-100 mg/l as N) have caused difficulties in the second stage digester at Penetanguishene. Because of the high solids concentration in the digester, very long settling times are required to obtain an appreciable amount of supernatant (e.g. one day of settling for a foot depth of supernatant). With settling times longer than one day, denitrification caused the settled sludge to rise to the surface, thereby eliminating the previous days' effort.

Field Measurements

In most cases, the process state of the digester can be established by the DO level, the ORP and the nitrate concentration. If all of these values are high, the process is normally performing satisfactorily. An investigation of the reliability of nitrate results indicates that this analysis should be conducted in situ or the sample should be filtered in the field for a subsequent laboratory analysis on the filtrate. The nitrate concentration, the DO in the digester and the ORP are all low in digesters that have not performed satisfactorily. Low DO levels are most common at high temperatures while at low temperatures there is usually no problem in maintaining a residual DO.

The digester oxygen utilization rates have ranged from 5.7 mg/l/hr at 21°C to 45 mg/l/hr at 25°C. Most rates are in the range of 10 to 35 mg/l/hr, the rate depending upon the digester solids concentration, the total sludge age (corrected for type of feed sludge), and the temperature. The oxygen requirements in terms of the specific oxygen uptake rate are discussed in another section.

B. PROBLEM AREAS

Mixing

All digesters under investigation were checked for adequacy of mixing, determined by the amount of solids deposition in the digesters. Since operation of the digesters requires the periodic removal of supernatant, mixing requirements for digesters must include the capability of resuspending settled solids that have accumulated during the settling period prior to supernating. Since settling characteristics of aerobically digesting sludges vary with the type of wastes being treated, long settling times may be necessary (i.e. twelve to twenty four hours) to obtain sufficient supernatant to permit further sludge wasting to the digester. Such extended periods of settling permit the deposition and compaction of solid material on the bottom of the digester.

The location of air diffusers in all digesters is normally 1.5 to 3 feet off the bottom. Sludge deposition in several digesters has been observed up to the level of the diffusers.

Data for bottom sludge samples in Table 5 are representative of bottom deposits related to the mixing capabilities of the air diffusers, except for the Aurora and Picton samples which actually were liquid contents at the bottom of the digesters. The low volatile fraction of the deposits in the Penetanguishene, Unionville, and Kleinburg plants suggests that the source of the deposits is grit. This is not the case for the Bolton plant where the cause of sludge deposition is the inadequate mixing capabilities of the air diffusers. Some deposition of grit can be expected because of the higher liquid velocities required to keep it in suspension but gross deposition of sludge should not occur. The ORP values are far lower than the values (i.e. less than 250 mv) that have been associated with satisfactory performance and a residual DO in the digesters and indicate the anaerobic conditions that exist in the bottom sludges.

It is believed that solids deposition in the digesters is due to a number of factors among which are the method of operating the digester, tank configuration, location of air diffusers, solids concentration in the digester, and type of sludge fed to the digester.

One digester has experienced no solids deposition, namely the Aurora digester. This is especially unusual since this digester has the lowest volumetric air supply - 8.4 cfm/ 1000 cu ft of digester capacity. The lack of solids deposition could be due to the physical design or due to the fact that the air supply for the Aurora digester is never shut off as a part of the normal operating procedure. Supernating is carried out in a separate unaerated tank (converted secondary clarifier) on a daily basis. The conical bottom of the digester and the placement of the air diffusers in the centre of the tank probably account for the good mixing characteristics even with low air flow rates.

Digesters experiencing the greatest problems of solids deposition include the Bolton, West Don and Unionville plants. All of these plants are conventional activated sludge plants and sludge wasting to the digesters is from the primary clarifier. This could account for some of the solids deposition in that inert material not removed in the grit removal facilities would settle out in the primary clarifier and be pumped to the digester. Bolton has had as much as forty inches of solids deposition directly below the air diffusers. Digesters associated with contact stabilization plants (Penetanguishene and Picton) have also had some solids deposition (excepting Aurora) though not to the extent of the plants mentioned above. At the contact stabilization plants, solids deposition has been more of a problem in the contact and reaeration zones than in the digesters.

Regardless of the source of deposited solids in the digesters, the result is the same; that is, loss of digester capacity. Aeration devices should therefore be capable of maintaining a solids concentration of 6 percent (maximum practical concentration in terms of oxygen requirements) in suspension and be able to resuspend this concentration following a long settling period.

Temperature Effects

Process temperature effects will be discussed in terms of the biological rates in a later section. Physical problems in the digesters have been encountered at the temperature extremes.

At high temperatures, foaming appears to be the major problem or most serious potential problem. When foaming occurs, supernatant removal becomes difficult. In addition, there is a nuisance problem with excessive foaming.

The presence of a foam layer has been observed on the surface of all aerobic digesters under investigation. The foam has generally not affected the operation of the digesters. The type of foam on the digesters under normal conditions is brown, dense, and appears and feels greasy. The foam is present throughout the year but normally to a lesser extent during the winter.

The quantity of foam present on a digester could not be correlated to the level of ether soluble material in the digesting sludge since high ether soluble concentrations have been observed without foaming problems. The only common parameter that has been observed at times when foaming has become a problem is the high liquid temperature. While the higher temperature is unlikely to be the cause of the foaming, it appears that it is a condition necessary for the formation of foam in excessive amounts.

The exact cause of foaming has not been determined or thoroughly investigated. It is possible that the foaming is due to detergents, ether soluble material, products of biological decomposition of the sludge or a combination of these and other causes.

At low temperatures, (0°C) ice formation in several digesters has caused operational problems. The most serious icing problem occurred at Bolton where the temperature of the digester contents was measured as -0.5°C. A piece of ice approximately 15 to 20 feet in diameter formed in the digester. The motion of the ice resulting from the liquid turbulence and wind occasionally carried it from the centre into the side of the tank breaking off the air diffuser drop pipes which are located around the circumference. Six of the sixteen drop pipes were broken off during a two week period.

Icing was also encountered at Unionville. During winter operation, the surfaces of the digesters have been covered with 6 to 8 inches of ice or with a mixture of frozen foam and ice making the determination of the amount of supernatant formed extremely difficult.

Frozen valve problems have been experienced at Bolton and Penetanguishene. In both cases, an exposed liquid filled section of pipe preceded the valve which is used on an intermittent basis.

Metal Toxicity

Metal analyses were carried out on all digester contents as well as the occasional supernatant sample. Since toxicity is primarily due to metal ions, several digester samples were filtered to determine the concentration of metals in solution. The data were collected to establish whether industrial wastes were affecting the performance of the Aurora and West Don digesters. All other plants with aerobic digesters have very few sources of industrial wastes and therefore provide a basis for comparison. The West Don and Aurora plants, with minimal sludge storage, waste sludge from their digesters more frequently than any of the other plants so that the accumulation of metals in the sludge will be much less for these digesters. Even considering this, both of these digesters normally contain high concentrations of metals.

Analysis of filtered samples indicates that the concentration of heavy metals in solution is extremely low. Filtrate samples for the West Don digester were not available because of the difficulty in filtering the sludge. However, analysis of a supernatant sample indicates that the concentrations of the most toxic metals (Cu, Cr, Ni, Zn) are below the level (5 mg/l) normally considered as the minimum concentration for toxicity (See Appendix I). While the concentration of metals in solution is low in all digesters, this does not necessarily suggest that the metals combined in the sludge do not have an inhibitory effect on the digestion process. Bottom sludge samples further indicate that the metals are concentrated in the sludge. The high concentration of toxic metals in digested sludge from plants receiving industrial wastes (i.e. metal wastes) could pose a problem if land disposal is the method of ultimate disposal.

Levels of metal toxicity for aerobic digesters were not investigated since this aspect of digestion is beyond the scope of this project. At present, such levels have not been established. The data on the digesters not subjected to

sources of industrial wastes (i.e. all except Aurora and West Don) give an idea of the metal concentrations that can be tolerated and still provide satisfactory performance. The poor performance of the Aurora and West Don plants cannot be attributed solely to the high metal concentrations since both digesters normally suffer from an oxygen deficiency.

Ultimate Sludge Disposal

Waste sludge from the aerobic digesters under investigation is ultimately disposed of on farm land except at the West Don plant where a sanitary landfill site is used.

Two of the plants (Bolton and West Don) have sludge drying beds but they are useful only on a seasonal basis. Both plants have experienced operating problems with the drying beds. The practical application of the sludge drying beds is possible for a very limited period of the year. Sludge applied to the beds normally requires at least two weeks under favourable drying conditions before a dried cake can be removed. Since such weather conditions are realized only during the summer months, uncovered sludge drying beds are an unreliable means of dewatering digested sludges. While covering the beds could extend their utility into the spring and fall months, the beds would still be of no service for approximately five months of the year because of freezing problems during the winter. It should be remembered that sludge from most aerobic digesters in the winter is only slightly above the freezing point (normally not greater than 5°C) and would probably freeze before there was any substantial drainage. It is felt that the cost of installing sludge drying beds would be better spent on providing additional storage capacity for digested sludge during the winter when most land disposal areas are inaccessible.

All plants are hauling or have hauled liquid waste sludge. Only Aurora hauls sludge on a daily basis and this must be discontinued at times during the winter when heavy snow prevents access to the disposal area.

While all plants disposing of waste sludge on farm land are receiving primarily domestic wastes (except Aurora which receives a greater proportion of industrial wastes), it is felt that the composition of the sludge should be periodically

checked to ensure that the sludge will not have a long term detrimental effect on the land with respect to its agricultural value.

Although the filterability of aerobically digested sludges was not determined on a comparative or quantitative basis, the sludges at all plants were filtered to obtain filtrate samples for certain analyses (metal analyses, nitrates, etc.). In all cases, Whatman No.3 filter paper was used and a vacuum was drawn either with a vacuum pump or an aspirator. On this basis then, all sludges filtered poorly. It was possible to obtain only 5-100 ml of filtrate before the filter paper was blinded by the cake. In one case (Kleinburg), the supernatant obtained after a settling period of one hour was filtered with only slightly better results. At two other plants, (West Don and Unionville) the filter paper blinded almost immediately.

While sludge conditioning would undoubtedly improve the filterability, it is felt that any full scale installations of filtration equipment in association with aerobic digesters should be preceded by extensive tests on digesting sludges from full scale plants.

C. DESIGN CONSIDERATIONS

Oxygen Requirements

The oxygen uptake rate of aerobically digesting sludge depends upon the temperature, the type of sludge fed to the digester and the sludge age of the digesting sludge. In order to compare the digesters on an absolute basis, all oxygen uptake rates have been determined and reported as specific uptake rates (mg O_2/gm volatile suspended solids/hour). In comparing specific uptake rates of the various plants, it is important to note that the treatment process associated with the aerobic digester governs the sludge age of the solids being wasted to the digester. The sludge age of conventional waste activated sludge is approximately 3 to 5 days, but with contact stabilization, the sludge age of all solids undergoing aeration is approximately 10 days. For an extended aeration plant the sludge age of the activated sludge solids is 20 to 25 days. Raw primary sludge has undergone no aeration. Therefore, sizing

a digester on the basis of the solids loading without considering the type of solids being wasted could lead to oversizing the digester for extended aeration plants which would cause no process problems. However, for conventional activated sludge plants, the load due to primary sludge could cause an oxygen deficiency due to an undersized digester.

The specific uptake rate in the first stage and single stage aerobic digesters ranged from 0.5 to 6.3 mg O_2/gm VSS/hour. The range for second stage digesters was 0.5 to 2.4 mg O_2/gm VSS/hour. Most of the data for first stage and single stage digesters are in the range of 2 to 4 mg O_2/gm VSS/hour. The digesters used with conventional plants have specific uptake rates that are approximately 50 percent greater than digesters used with contact stabilization plants.

From these uptake rates it can be seen that the most severe oxygen demand arises from primary sludge. Not only is the specific uptake rate higher but the waste solids concentration is also higher. Since the primary sludge is a food source for the biological system in the digester, synthesis of additional sludge will occur in the digester. This represents a continuing high oxygen demand in addition to the initial immediate oxygen demand. On this basis, it is felt that aerobic digestion is not well suited to the stabilization of primary sludge. If aerobic digestion is used for primary sludges, a two stage system would be a necessity in order to keep the solids concentration to a minimum in the first stage and to ensure that sludge wasted from the digesters is stabilized. Even with contact stabilization plants, a two stage aerobic digestion system is required to obtain a stabilized sludge. With extended aeration plants a single stage digester would be adequate since present indications are that the waste activated sludge from this type of plant is equivalent to sludge from a first stage or single stage digester.

It has been found that digested sludges with specific uptake rates between 0.5 to 1 mg O_2/gm VSS/hour were well stabilized (i.e. did not putrefy when left unaerated). At very low liquid temperatures (less than 5^{o}C), this range of uptake rates would not necessarily indicate sludge stability but ultimate sludge disposal would probably be extremely difficult when such temperatures occur.

In Figure 1 the specific uptake rate has been plotted against the sludge age of the solids undergoing digestion. The sludge age used for this graph is the total sludge age of the solids; that is, the sludge age of the digester solids plus the sludge age of the solids as wasted to the digester. Many of the sludge ages were estimated (an exact figure is impossible to obtain due to the variations in waste sludge concentrations and the frequency of ultimate disposal); however, it is felt that the values calculated are representative of the process conditions and do not seriously affect the conclusions derived from the graph. The data have been grouped into two temperature ranges, below 10°C and above 10°C. The digesters (except Aurora) are below 10°C for approximately five months in the winter. Figure 1 therefore corresponds to summer and winter operating conditions. It can be seen that with short detention times, the temperature very seriously inhibits the rate of biological activity. With long detention times (greater than 120 days total sludge age), the biological activity is so low that the temperature has little additional effect. It is also felt that the temperature effect is greatest in the range of 0-5°C with little effect on process biological activity between 10 and 25°C. At the very high temperatures which are occasionally encountered (i.e. greater than 25°C), the process would be affected to the greatest extent by the inability of the aeration equipment to supply a residual DO.

From the graph it can be seen that a total sludge age of approximately 150 to 180 days is required before the rate of biological activity reaches a minimum. Digested sludges with these sludge ages have been observed to be well stabilized. Such sludges have an earthy, slightly musty odour and do not putrefy when left unaerated.

In order to achieve such sludge stability a two stage digester would be a practical necessity except for extended aeration plants. At a specific uptake rate of 2, a second stage digester at 6 percent total solids (assume 50 percent volatile) would require an air supply of 67 cfm/1000 cu ft of digester capacity (assuming 5 percent transfer efficiency). At a total sludge age of 30 days, a first stage digester operating at a specific uptake rate of 3.5 and a solids concentration of 2.5 percent (assume 50 percent volatile) would require an air supply of 49 cfm/1000 cu ft of digester capacity

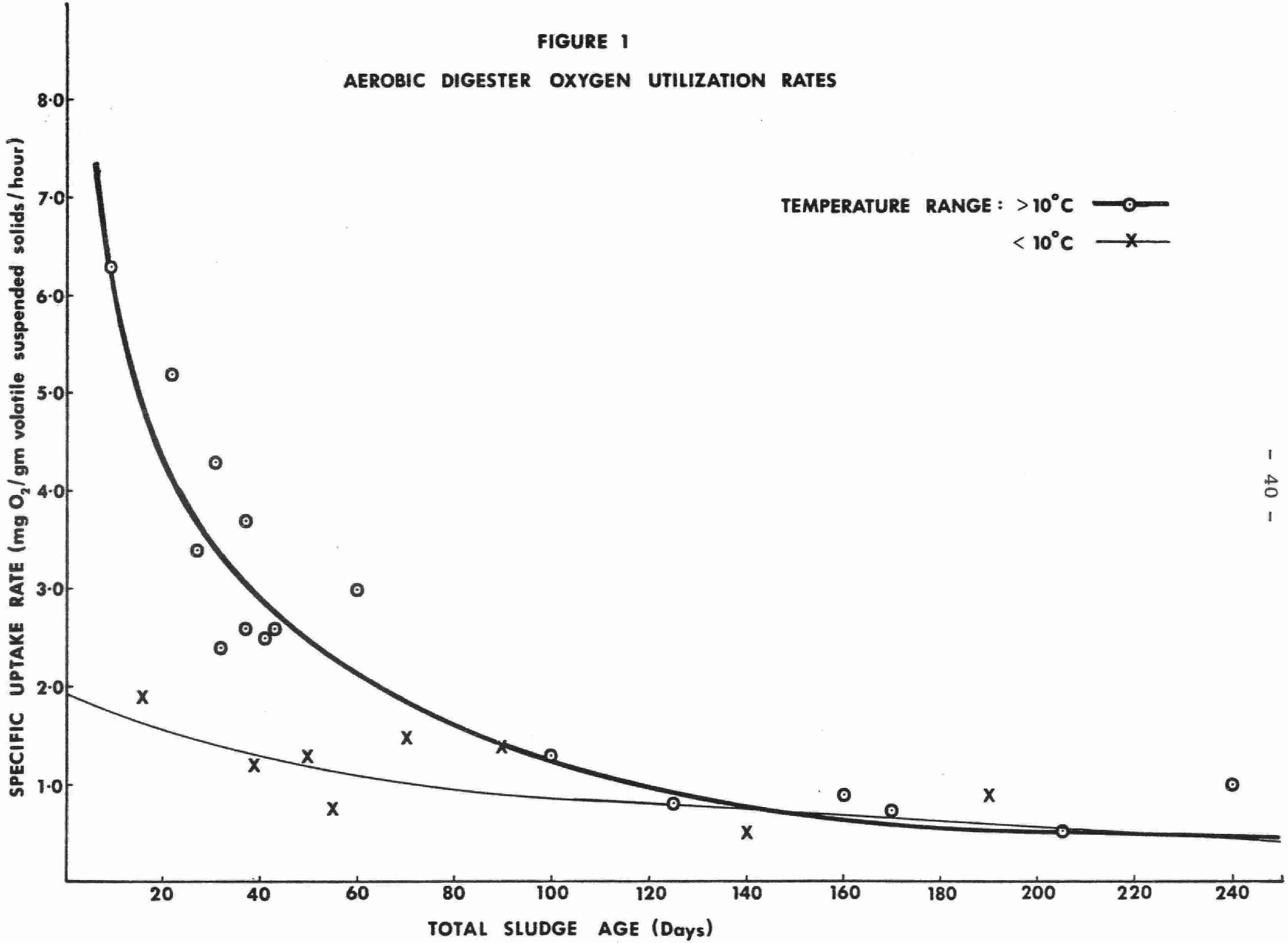

FIGURE 1

AEROBIC DIGESTER OXYGEN UTILIZATION RATES

(assuming 5 percent transfer efficiency). The examples chosen represent the maximum oxygen requirements that should be encountered with aerobic digesters and indicate that an air rate of 50 to 60 cfm/1000 cu ft of digester capacity should be provided. If a greater solids concentration is to be carried in the digesters or if shorter total sludge ages are considered, then higher air rates will be necessary.

Since these examples have been calculated using the total sludge age, the type of sludge wasted to the digester must be considered to establish this sludge age. For a first stage digester providing a total sludge age of 30 days, the full 30 days would be required for waste activated sludge from conventional plants and approximately 20 days would be necessary for waste activated sludge from contact stabilization plants. The sludge age and hydraulic retention time are the same only when the waste sludge solids concentration is the same as the digester solids concentration. The hydraulic retention time is relatively unimportant as long as a sufficient solids retention time is provided.

Sludge Wasting and Supernatant Removal Procedures

In order to waste sludge to the digester, some of the digester contents, preferably as supernatant, must first be removed. This may be accomplished by shutting off the air supply to obtain supernatant. This is either removed before sludge wasting or displaced by the waste sludge fed to the digester. The supernatant is returned to the plant influent or one of the treatment zones. By locating valves at fixed levels for supernatant removal, it is assumed that a particular amount of supernatant can always be obtained. Swing valves offer greater flexibility for the variations that are inherent in this process since they allow the removal of all the supernatant from digesters with diffused air aeration devices. However, removal of a large fraction of the tank volume (i.e. greater than 25 percent) is not desirable since these aeration devices depend upon the liquid depth for most of their oxygen transfer. It is therefore desirable to operate the digester at or close to its maximum depth at all times.

Sludge transfer from the first to second stage digester is normally accomplished by removing supernatant from the second stage, allowing the first stage to settle, and then transferring the concentrated sludge by the head difference. Following the transfer, supernatant can be removed from the first stage digester. This transfer is required when the solids concentration in the first stage increases, resulting in poor settling or an oxygen deficiency (normally about 3 percent total solids). If a concentrated sludge is expected following aerobic digestion, two stage digestion is a necessity. Such a system also offers greater flexibility in operation. A separate tank could be used for supernating and denitrification but this would be an additional cost.

The basis for wasting sludge from aerobic digesters has been either of two criteria, both of which are inadequate as far as the process is concerned. The first of these criteria is that the digester is full and the poor sludge settleability does not permit the wastage of additional sludge to the digester. The second criterion is that the solids concentration is extremely high and the maximum air flow cannot supply a residual DO. In both cases, sludge must be hauled for ultimate disposal. However, the sludge may not be stabilized.

Two methods of determining the stability of the digested sludge are by the percent reduction of volatile suspended solids and by the specific uptake rate. The percent reduction of volatile suspended solids would require a regular check (at least once a week) on the volatile fraction of the waste sludge to the digester so that erroneous conclusions on the degree of digestion would not be drawn due to periodic fluctuations in the volatile fractions. Also, the volatile fraction in sludges undergoing digestion for long periods of time appears to reach a minimum value indicating a maximum volatile solids destruction of approximately 45 percent. This is thought to be due to a buildup of biologically inert volatile material in the sludge. The minimum equilibrium volatile fraction is dependent upon the initial volatile fraction of the waste sludge. Results on full scale digesters indicate that volatile solids reduction is not a reliable means of determining digested sludge stability as can be seen from the results in Table 7.

The specific uptake rate is a more reliable indication of digested sludge stability since it is a measure of biological activity. Since the purpose of the aerobic digestion process is to biologically oxidize organic compounds to stable organic and inorganic end products and the biological activity decreases as the unstable organic fraction of material in the sludge decreases, then this measure of biological activity (specific uptake rate) is an absolute basis of sludge stability that is not peculiar to an individual plant. Figure 1 shows the effect of sludge age and temperature on the specific uptake rate. While this rate is temperature dependent, it is still possible to select a level of activity, depending upon the temperature, that indicates that a sludge is sufficiently stabilized for purposes of ultimate disposal. Since the degree of stabilization necessary for ultimate disposal depends to a great extent upon the local conditions, the specific uptake rate that indicates stability for the local conditions can be established by individual plants. A specific uptake rate less than 1 usually indicates a stable sludge.

This rate represents stability considering the aerobic digestion process as a unit process. The size of digester required to meet these process demands would usually make the process uneconomical. The stability required for sludge disposal depends upon the method of ultimate disposal and the local conditions. Where land disposal of sludge is practiced, total sludge ages as low as 45 days would be accepted. If local conditions require a more stable sludge, a total sludge age of 90 days should be adequate.

Determination of the specific uptake rate requires a dissolved oxygen meter for measuring the oxygen utilization rate and equipment for the determination of the volatile solids concentration. While a balance, an oven and filtration apparatus are desirable, a centrifuge will give a rough indication of the volatile solids concentration from the centrifuge tube reading provided periodic checks on the volatile fraction of the digester suspended solids are made. Such equipment should be considered essential if meaningful process control of the activated sludge system and aerobic digesters is expected. The cost of this equipment will normally be less than 1 percent of the total plant cost.

General Design Considerations

The operational problems of seasonal temperature variations have been discussed previously. Factors that affect the temperature operating range of aerobic digesters include the hydraulic retention time, heat sources and heat sinks in terms of the air supply and the sewage flow through the treatment plant, and the construction characteristics of the digester.

The air temperature from air blowers is usually in excess of 150^{o}F. This heat source has not been utilized in the past. Insulation of the air lines and minimizing the length of air lines could conserve this available heat to prevent freezing problems in winter. Perhaps the easiest method of preventing temperature extremes is the use of common wall construction. The temperature of raw sewage is usually greater than 5^{o}C. Having steel digester walls in common with the aeration tanks (or some other treatment zone through which the plant influent flows) will ensure that the digester temperature will be only slightly lower than the temperature of the raw sewage. During the summer extremely high digester temperatures will be avoided. Where common wall construction is not possible, alternate methods of heat conservation that can be considered include placing the tank below grade, providing earth embankments around the tank and/or covering the digester. In extremely cold areas, consideration should be given to heating the digester especially if a well stabilized sludge is required.

The maximum temperature range observed in aerobic digesters was 29C^{o} (0^{o} to 29^{o}C). In plants that have instituted some of the above factors for minimizing the temperature variation, the range has been as little as 11.5C^{o} (13.5^{o} to 25^{o}C). The physical design becomes especially important if mechanical aerators are considered since one potential heat source available with diffused air systems is lost. Therefore, it is felt that their use should be avoided unless a heat source is available. The use of fine bubble diffused air aeration devices should also be avoided since the frequently repeated periods of settling prior to supernating affords too great an opportunity for plugging. Coarse bubble diffusers of a design that is not prone to plugging should be used. Since no assurance can be given that plugging will not occur, the diffuser mountings should permit removal of the units without draining the digester.

As well as providing sufficient oxygen for biological activity, the aeration device must also be able to keep a high solids concentration (approximately 6 percent maximum) in suspension and resuspend the solids after the settling period.

Plant expansions where anaerobic digesters are currently in use should consider using both aerobic and anaerobic digestion; aerobic digestion for waste activated sludge and anaerobic digestion for primary sludge. Aerobic digestion could possibly eliminate the need of increasing the anaerobic digestion capacity.

CONCLUSIONS

1. The aerobic digestion process can produce a stable sludge. The design should provide a sufficient solids retention time rather than a specific hydraulic retention time. Air requirements will depend on the solids retention time and maximum solids concentration in the digester.

2. While a reduction of volatile solids does occur during aerobic digestion, the percent reduction of volatile solids cannot be used to indicate the stability of sludges from digesters under continual loading conditions. The specific oxygen uptake rate is one of the most reliable indicators of the conditions and stability of aerobically digested sludge. This rate is temperature dependent.

3. Aerobic digestion produces a low organic strength supernatant which represents an insignificant load when returned to the activated sludge process. Nutrient return from aerobic digesters normally represents less than 5 percent of the total plant nutrient flow.

4. To ensure sludge stability and to effect concentration of the sludge, a two stage digestion system is required for all activated sludge processes except the extended aeration modification. Settling characteristics of digesting sludge deteriorate with increasing solids concentrations and low residual DO levels.

5. Present air flow rates (20 cfm/1000 cu ft of digester capacity) have resulted in solids deposition and oxygen deficiencies in some digesters.

6. Operational problems occur with extremes of temperature. Foaming has occurred at high temperatures and icing at low temperatures. Temperature extremes in the digester can be minimized by the physical plant design.

7. Sludge drying beds are impractical for use with aerobic digesters in our climate.

RECOMMENDATIONS

1. The following items should be considered essential to the proper design of aerobic digesters:

    (a) the necessary solids retention time (total sludge age) to produce a sludge of acceptable stability should be provided.

    (b) two stage digestion should be provided for all but extended aeration plants.

    (c) the physical design should minimize temperature extremes.

2. The aerobic digestion process should be considered principally for waste activated sludge.

3. Air supplies for aerobic digestion should be based on the oxygen utilization rate at a particular sludge age at the maximum solids concentration and the maximum operating temperature.

4. The use of aerobic digestion for industrial wastes sludges should be preceded by treatability studies.

APPENDIX I

METAL ANALYSES

Plant and Location	Total Solids	Cr	Al	Zn	Cu	Ni	Pb	Cd	Mn	Fe
Penetang										
#1 Digester	21100	0.30	-	5.3	0.0	1.0	0.0	-	-	-
#1 Digester	20100	1.0	-	22.0	8.6	5.3	9.2	0.7	15.0	15.6
#1 Digester - filtered	-	0.0	-	0.1	0.0	0.0	0.0	0.0	0.0	0.07
#2 Digester	31500	0.30	-	22.0	6.1	2.0	0.0	-	-	-
#2 Digester	29400	2.0	-	39.0	15.0	5.3	17.0	0.7	28.0	675
#2 Digester - filtered	-	0.0	-	0.01	0.0	0.02	0.0	0.0	0.0	0.06
Reaeration Zone										
Bottom Sludge	645000	6.0	-	217	42.0	32.0	48.0	7.4	70.0	2800
Bolton										
Digester	14300	0.0	-	9.5	2.6	3.2	1.5	0.1	12.8	200
Digester Supernatant	(328)*	0.0	-	0.4	0.04	0.54	0.3	0.10	0.78	2.7
Digester - bottom sludge	698000	11.0	-	320	150	160	28.0	3.7	600	19000

*Denotes suspended solids

All results in mg/l

cont....

APPENDIX I (cont)

Plant and Location	Total Solids	Cr	Al	Zn	Cu	Ni	Pb	Cd	Mn	Fe
Aurora										
#1 Digester	24600	120	2400	18.5	12.0	0.8	7.7	0.0	11.4	230
#1 Digester - filtered	-	< 0.01	0.28	0.0	0.01	0.0	0.0	0.0	0.16	0.10
#1 Digester	28600	83.0	2275	15.0	-	-	4.8	0.0	-	160
#2 Digester	25400	150	2500	15.0	10.0	0.7	5.4	0.0	9.4	210
#2 Digester - filtered	-	< 0.01	0.38	0.0	0.03	0.0	0.0	0.0	0.0	0.14
Raw Sewage	940(220)	0.35	13.8	0.28	0.08	0.0	0.0	0.0	0.02	1.1
Final Effluent	1020(70)	0.23	10.5	0.08	0.07	0.0	0.0	0.0	0.03	0.44
West Don										
Digester	14900	38.0	-	40.0	21.5	11.7	59.0	0.24	7.2	500
Digester	31600	60.0	-	4.3	2.1	1.4	3.3	0.03	1.1	112
Digester Supernatant	2240(646)	0.14	-	3.0	0.0	0.0	0.0	0.0	3.0	54.0
Digester	34300	17.5	840	80.0	63.0	15.7	77.0	0.6	22.0	1680
Primary Effluent	-	0.15	2.40	2.8	0.08	0.46	2.0	0.0	0.16	8.8
Final Effluent	-	0.10	1.05	0.7	0.0	0.05	0.6	0.0	0.17	7.2

All results in mg/l

cont....

APPENDIX I (cont)

Plant and Location	Total Solids	Cr	Al	Zn	Cu	Ni	Pb	Cd	Mn	Fe
Kleinburg										
Digester	47400	3.0	-	41.0	24.0	4.0	0.0	0.95	27.0	1120
Digester	44600	0.9	1125	42.0	46.0	3.3	1.5	0.8	28.0	640
Digester - filtered	(5)	0.0	0.21	0.08	0.11	0.0	0.0	0.0	0.0	0.20
Digester - millipore filtered*	-	0.0	0.14	0.03	0.0	0.0	0.0	0.0	0.03	0.04
Digester - bottom sludge	162000	2.45	5250	580	640	40.0	70.0	2.0	580	21600
Raw Sewage	-	0.0	3.25	0.18	0.14	0.0	0.0	0.7	0.17	4.0
Final Effluent	-	0.0	0.78	0.06	0.03	0.0	0.0	0.0	0.04	0.56
Picton										
#1 Digester	12700	1.0	-	12.0	4.2	0.0	3.8	0.0	1.8	58.0
#1 Digester - filtered	-	0.0	-	0.13	0.0	0.0	0.0	0.0	0.12	0.04
#2 Digester	7200	0.5	-	11.3	4.2	0.0	0.8	0.0	1.4	60.0
#2 Digester - filtered	-	0.0	-	0.08	0.0	0.0	0.0	0.0	0.7	0.08
Unionville										
#1 Digester	9980	<0.01	55.0	11.0	10.0	0.0	0.0	0.0	0.33	110
#2 Digester	11700	0.096	48.0	11.5	11.3	0.0	0.0	0.0	0.30	120

*0.45 microns

All results in mg/l

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